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## A SYNOPTIC CHARACTERIZATION OF THE THERMAL NATURE OF THE EARTH'S SURFACE<sup>1</sup>

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### ABSTRACT

In view of the interrelated nature of component parts of the atmospheric circulation, it is suggested that surface-atmosphere interaction studies should be hemispheric in scope for time intervals beyond a few days. Hemispheric data sources for potentially important surface conditions—sea-surface temperature, snow cover, sea-ice extent, and soil moisture—are discussed and an example of the extent of such data as are readily available is given. This example is discussed in conjunction with the evolving circulation pattern in terms of the origin of anomalous surface conditions and their possible effects. The role of anomalous surface features in relation to November to December climatological persistence is discussed for two regions on the basis of conditions in November and December 1959.

### 1. INTRODUCTION

Throughout the history of meteorology there have been persistent attempts to relate abnormal conditions at the earth's surface to the subsequent atmospheric circulation or weather. Factors such as the extent of polar sea ice, the anomaly of sea-surface temperature, and the depth or extent of snow cover have received individual attention. Early studies of this nature were prominent in the survey of long-range forecasting methods [14] undertaken prior to the inception of systematic extended forecasting by the U.S. Weather Bureau. One phase of the problem, large scale ocean-atmosphere interaction, has recently been extensively surveyed [11]. Present day studies involving the interaction between the ocean surface and overlying atmosphere include those on a decadal scale by Bjerknes [2], on a monthly and seasonal scale by Namias [15], and on a short time scale by Petterssen, Bradbury, and Pedersen [20]. Namias [16] has also dealt with the effects of extensive snow cover and dry and wet land surfaces.

In studies of this nature it would appear that, as the time scale lengthens, the necessity for a hemisphere-wide

approach increases due to the interrelated nature of the various segments of the atmospheric circulation. That is to say, the response of the atmosphere to anomalous surface conditions in various parts of the hemisphere can be in concord or opposition depending upon the initial state of the atmospheric circulation and its course of development; with the passage of time such mutually strengthening or debilitating influences spread to increasingly distant areas. The possibility of a hemisphere-wide approach in surface-atmosphere interaction studies is enhanced by present sources of hemispheric weather data, extensive measurements of sea-surface temperature, modern data processing methods, satellite potentialities, and the continuing attitude of international cooperation in the field of meteorology.

The present paper describes an effort to assemble all pertinent, readily-available information bearing on the anomalous thermal nature of the earth's surface at monthly intervals during the period, November 1959 through May 1960. Data sources and processing are touched upon and the abnormal thermal nature of the earth's surface is viewed in conjunction with the developing monthly mean circulation in terms of the origin of the anomalous conditions and their possible future influences upon the circulation and weather.

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## 2. MAPPING THE THERMAL ABNORMALITY OF THE EARTH'S SURFACE

Of the many variations in thermal properties at the earth's surface which could affect the energy available to the atmosphere, consideration can be focused upon those factors whose effects appear to dominate, and for which there is a reasonable supply of readily available data. A number of workers (e.g. Houghton, [7]) have indicated that the following factors are apt to be most important: (1) anomaly of the sea-surface temperature, (2) extent of snow cover in middle latitudes, (3) extent of sea ice, and (4) extreme changes on soil-moisture content. Data on all of these variables, except soil moisture, are available over portions of the Northern Hemisphere. In the case of soil moisture, estimates of evapotranspiration and soil-moisture storage can be obtained from hemispheric precipitation and temperature data.

When the work described in this paper was initiated, sea-surface temperatures were available for sizable ocean areas in the form of 10-day or monthly-mean charts. Data sources include charts of the Japan Meteorological Agency [8], the Bureau of Commercial Fisheries [3], the U.S. Navy Hydrographic Office [28], and the Denmark Meteorological Institute [5]. Recently, automated synoptic analyses of daily sea-surface temperature charts by the U.S. Navy (Fleet Numerical Weather Facility, Monterey, Calif.) have become a reality, and represent potentially a very valuable source of timely and extensive sea-surface temperature data.

Of the mean sea-surface temperature analyses cited, only those of the Japan Meteorological Agency, through facsimile transmission, are disseminated with operational use in mind; analyses of the Bureau of Commercial Fisheries are available in published form with little delay. Both of these analyses pertain to middle latitudes over the North Pacific Ocean. Thus the lack of timely mean temperature analyses for the Mediterranean Sea, the tropical waters south of  $15^{\circ}$  to  $20^{\circ}$ N. latitude and the North Atlantic is a serious deficiency. Ship reports from the North Atlantic Ocean are, however, readily available and generally numerous.

The normal background against which sea-surface temperatures can be viewed has been extensively treated (e.g., U.S. Navy Hydrographic Office [24]).

Provisions have been made for the inclusion of snow depth or state of the ground information in meteorological reports in appropriate regions of the earth. However, in the Northern Hemisphere such data are deleted prior to overseas transmission, making synoptic depiction of hemispheric snow extent difficult. This is a serious data limitation in view of the large variation in thermal properties across the snow boundary.

In certain remote areas snow cover data are, of course, completely lacking. Studies relating 1000–500-mb. thickness to snow boundary allow a rough estimation of snow boundary in such areas. Lamb [10] found the snow

boundary in Europe to be associated with an average 1000–500-mb. thickness of 17,297 ft. with a standard deviation of 170 ft. In the United States, 1952–61 data indicate that the thickness accompanying the 1-in. snow boundary averages 17,550 ft. in nonmountainous areas and 18,000 ft. in the western mountains with standard errors of 330 ft. and 240 ft., respectively. As would be expected, United States values do not differ greatly from, but are less than, the thicknesses associated with an equal probability of solid and liquid precipitation in the United States [19].

The normal extent of snow cover throughout the year has been investigated for much of the Northern Hemisphere [1], for Sweden and Finland [4], and for China [17]. In addition, detailed maps dealing with the probability of snow cover in the United States have been prepared by the author from station record book data.

The extent of sea ice over portions of the Arctic area is routinely analyzed by the U.S. Navy Hydrographic Office [26] on the basis of Canadian, Danish, and United States aerial reports. Additional analyses are ultimately published by Denmark [5] and by Great Britain [6]. For the Barents Sea, an area of much interest and moderate variability of ice extent, timely analyses of ice extent do not appear to be available. This is the case, also, in the area eastward from the Barents Sea to the Bering Straits where variability of the ice boundary is confined to the warmer portion of the year. Charts portraying the normal extent of sea ice are readily available (e.g., U.S. Navy Hydrographic Office [25], [27]).

Despite its direct applications to hydrologic forecasting and agricultural meteorology, soil moisture has not been generally included in meteorological observation programs. Undoubtedly one reason for this is the very time-consuming nature of the conventional gravimetric method of soil-moisture measurement which to some extent has now been supplanted by the use of tensiometers, electrical resistance devices, and most recently, neutron flux methods. At the present time soil-moisture measurements are usually relegated to the domain of the Agricultural Experiment Station where dissemination of data awaits the publication of research results.

Fortunately, methods have been developed (e.g., Penman [18] and Thornthwaite and Mather [23]) by which evaporation and soil-moisture storage can be estimated from meteorological observations. The methods of Thornthwaite are especially attractive since they require only the readily available temperature and precipitation data and have been shown to give reasonable results (e.g., Smith [21], Marlatt, Havens, Willits, and Brill [12]).

In the present study soil moisture has been estimated for a hemispheric network of stations using Thornthwaite's methods. A simplifying assumption is made that all soils hold 300 mm. of plant-available water at field capacity. Inherent in the Thornthwaite technique are the additional assumptions that no runoff occurs until the soil reaches field capacity and that actual evapotranspira-

tion is proportional to available water in the soil. The reader is referred to publications of the Laboratory of Climatology [22], [30] for justification of assumptions. Computations have been made using monthly precipitation and mean temperature data [29] and thus provide soil-moisture estimates at the end of each month. These estimates can be viewed in conjunction with the normal soil-moisture storage computed from normal temperature and precipitation data. Although such soil-moisture estimates are far from perfect, it is felt that the grosser aspects of the hemispheric soil-moisture pattern are thus revealed.

### 3. AN EXAMPLE

The type of information which can be readily accumulated regarding the anomalous thermal nature of the earth's surface in the Northern Hemisphere is illustrated for November 1959 in figure 1. Over the oceans, departure from normal of monthly average sea-surface temperatures are given except for the western Pacific where average temperature for the middle decade of the month is utilized. In the Greenland area the anomalous extent of sea ice covering at least half the surface is outlined.

Over continental areas the extent of snow depth equal to or greater than 1 in. at the end of the month is shown, together with the line of 50 percent probability of that amount of snow on the ground at the end of November. In Asia, east of 77°E. longitude, the snow boundary is estimated from the 1000–500-mb. thickness analyses at the end of November. Finally, over southern portions of the continents, the field of soil-moisture storage anomaly has been analyzed based on computations at the indicated network of stations. Areas of probable maximum effect of anomalous soil moisture can be evaluated by viewing the computed soil-moisture anomaly pattern in conjunction with maps (not shown) giving normal values of precipitation minus potential evapotranspiration for the following month.

### 4. CAUSES OF ABNORMALITIES IN NOVEMBER 1959

The probable origins of the abnormal surface conditions of figure 1 can be discussed in connection with the middle and lower tropospheric circulation during November 1959 as depicted in figure 2. Observed temperature and precipitation referred to in the ensuing discussion were obtained from published monthly data [29]. Anomalous snow cover over the United States was related to the amplified upper-level ridge-trough pattern in that region, which flooded the country with cold air and favored extensive precipitation along the eastern slopes of the Rockies by upslope motion (note anomalous surface wind components from the east on fig. 2b), and to the east in the vicinity of the vigorous trough. A strong European blocking ridge with attendant warm air and lack of precipitation resulted in relatively sparse snow cover over northern Europe. Over the Barents Sea, air temperatures were 3° to 6°C. above normal, climbing above freezing. To the south,

the block essentially eliminated the normal mild westerly flow over eastern Europe, resulting in an extensive area of below normal temperatures. North of the Black Sea where November mean temperatures dropped below freezing and where cyclonic curvature aloft and enhanced south wind components assured some precipitation, the snow line advanced south of its normal position.

In response to the European blocking ridge, cold air swept southward during November, enveloping the middle latitudes of Asia. To the rear of the mid-Asian trough, with its strengthened northerly wind components, precipitation during November 1959 was almost non-existent and the snow line northeast of the Caspian Sea was far north of its normal early winter position. Although the exact snow boundary in middle and eastern Asia is unknown, thickness analysis at the end of November suggests a substantial protrusion of the snow boundary south of its normal position. This appears quite reasonable in view of the cold November temperatures coupled with the relatively intense trough aloft in that region. Substantiating evidence is also found in above normal snowfall amounts observed during November along the southern rim of Siberia and the sequence of pressure waves which moved eastward, south of the Asiatic continental anticyclone during the month as depicted on operationally prepared U.S. Weather Bureau hemispheric charts.

Over oceanic areas abnormal water temperatures appear related to the anomalous component of low-level atmospheric circulation through surface stress, in a manner described by Namias [15]. Drift of surface waters at an angle of 45° to the right of the anomalous surface geostrophic wind component (see fig. 2b) fairly well accounts for major areas of abnormal sea-surface temperatures. For example, consider the mid-Pacific where anomalous surface winds from the northwest would give rise to anomalous drift of surface waters from the north. The observed below-normal water temperatures in that area are in agreement with the expectation that such a drift would effect a southward displacement of cool water. It is not implied that anomalous wind stresses determine the sea-surface temperature pattern to the exclusion of such factors as upwelling, radiation, and evaporation. However, it is apparent that the main features of the mean sea-surface temperature anomaly pattern in this instance are qualitatively in quite good agreement with the effects of anomalous surface wind stresses.

The extent of sea ice in the Arctic regions is a complex function of ice production, ablation, and distribution effects integrated over several months.

Anomalous soil moisture content, depicted in lower latitudes on figure 1 is an expression of the interplay of evaporation and precipitation over several months time. The dry soils near Hong Kong, for example, resulted from an almost total lack of precipitation during October and November 1959 coupled with above-normal temperatures and associated high evaporation potential during both months.

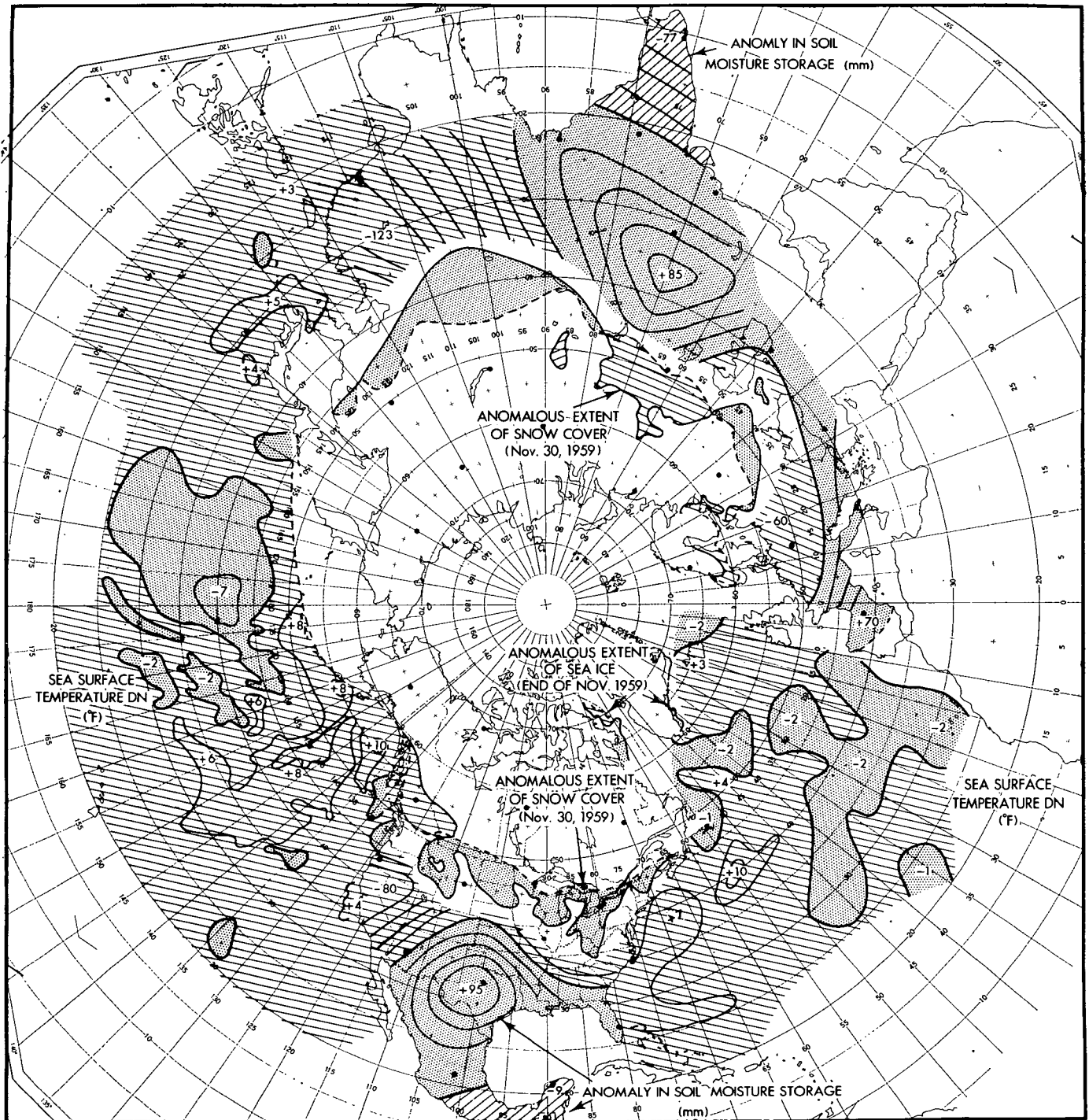


FIGURE 1.—Anomalous thermal nature of the earth's surface in the Northern Hemisphere in November 1959. Over the oceans departure from normal (°F.) of monthly (or middle decade, see text) average sea-surface temperature is shown together with sea-ice boundary near Greenland (solid line) and its normal location (dashed line). Over land surfaces the 1-in. snow boundary (solid line) and the line of 50 percent probability of snow cover at November's end (dashed line) are indicated. Over southern portions of North America and Eurasia the field of soil-moisture storage anomaly (mm.) is based upon computations at stations indicated by darkened circles. In all instances surfaces with warming effects, relative to normal, upon the atmosphere are cross hatched and those with cooling effects are stippled.

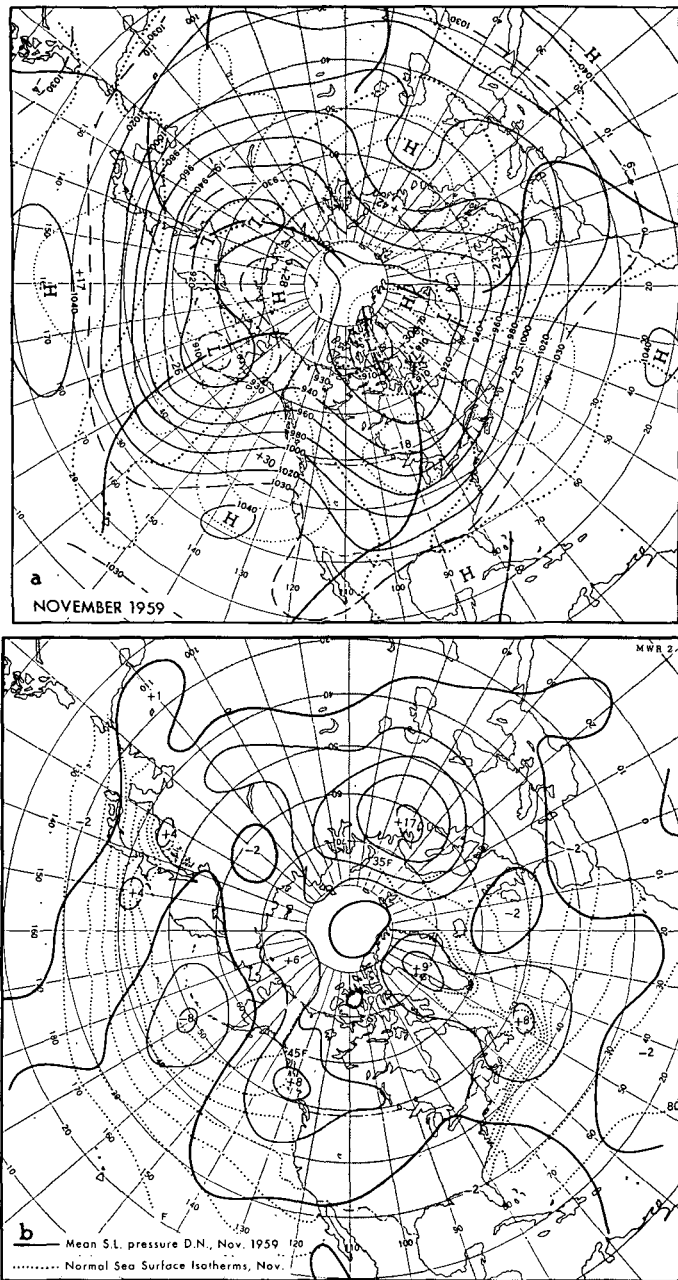


FIGURE 2.—(a) Monthly mean 700-mb. height (solid lines) and departure from normal (dotted lines), both in tens of feet, November 1959. (b) Departure from normal of monthly mean sea level pressure (mb.) for November 1959 (solid lines) and isotherms (°F.) of normal November sea-surface temperature (dashed lines).

### 5. POSSIBLE EFFECTS OF NOVEMBER 1959 ABNORMALITIES

Considering the evolving large-scale circulation from November 1959 (fig. 2a) to December 1959 (fig. 3), one can speculate upon possible effects of the anomalous surface conditions of November 1959 (fig. 1). Such speculation is useful to the degree that it promotes acquaintance

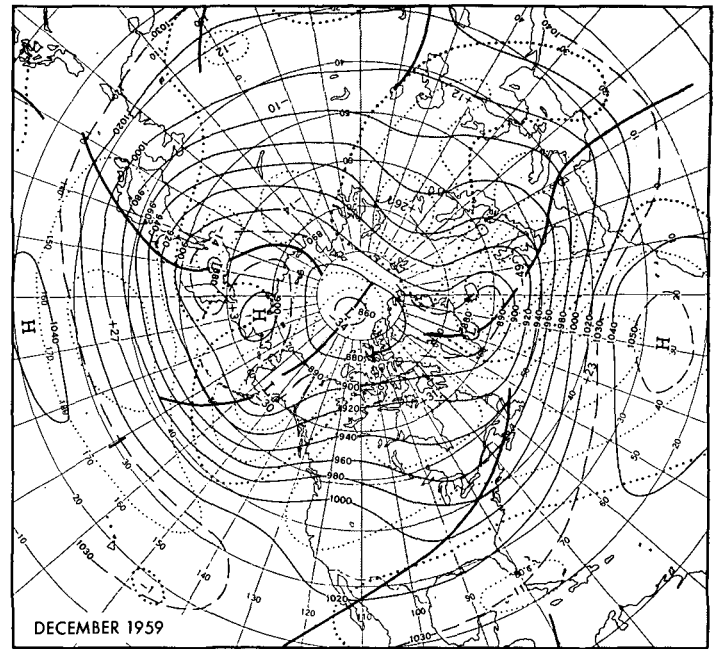


FIGURE 3.—Monthly mean 700-mb. height (solid lines) and departure from normal (dotted lines), both in tens of feet, December 1959.

with the type and scope of the interactions involved and suggests approaches amenable to quantitative attack.

Over Europe and Asia there was persistence from November to December 1959 of the European block—Asiatic trough complex, especially when viewed in terms of 700-mb. height departures from normal. This is not unusual since November monthly mean height departures from normal are highly correlated in a positive sense with those of December in these areas. Data on the surface thermal conditions at the end of November 1959, while fragmentary in nature, suggest a possible persistence-encouraging influence.

In the vicinity of the warm blocking High the sparse snow cover over Scandinavia would exert a warming influence relative to normal; however, the total area of snow cover deficiency is not known. Farther to the north, with air temperatures  $3^{\circ}$  to  $6^{\circ}\text{C}$ . above normal over the Barents Sea, as previously noted, it would be reasonable to expect water temperatures at least as warm as normal, which at this time of the year result in a crescent of warmth surmounting the cold European continent. Thus beneath the warm blocking High there were islands of warmth whose extent and magnitude are not well defined. In the region of the cold Asiatic trough, where an extensive area of anomalous snow cover has been inferred, persistence of the trough through direct thermal effects as well as through the stimulation of cyclonic activity along its eastern border would be encouraged.

With below normal heights persisting from November to December 1959 over eastern Asia, synoptic climatology [13] favors a weak Asiatic coastal trough, thus suppressing

any developmental potentialities inherent in the warm coastal waters.

The monthly mean upper-level trough located over the mid-Pacific during November, under the influence of seasonally increasing zonal westerlies pushed eastward to the Gulf of Alaska in December with central height of the 700-mb. Low dropping 250 ft. This sequence of events was described in a seasonal sense by Namias [15] who suggested that the longevity of a trough is aided by warm waters to its east which provide good sources of both heat and moisture and encourage cyclogenesis.

In the present case, the November to December height fall in the Gulf of Alaska was 400 ft. greater than normal. It seems quite probable that the exceptionally warm Gulf waters (up to 10°F. above normal) took part in this striking development somewhat in the manner described by Winston [31]. As the mid-Pacific trough moved eastward, cooler air moving over the warm Gulf waters was strongly heated, producing organized convection and an injection of cyclonic vorticity into the atmosphere. In conjunction with the eastward motion of the large-scale trough, there were frequent transient Lows deepening as they moved northeastward into the Gulf. It is likely that the contrasting warm and cool water surfaces of the eastern Pacific contributed to the zone of thermal contrast along which these storms developed.

It may be mentioned that this is an example of large-scale development with feed-back implications which has occurred several times in past November-December sequences. This appears to be one of the preferred circulation developments from November to December which contributes to the tendency toward non-persistence of November cold weather over much of the United States, a fact demonstrated by Landsberg and Appel [9].

In the present case, below normal November temperatures in the United States, associated with a strong ridge along the west coast of North America gave way to warm December temperatures as recurrent Gulf of Alaska Lows effectively reduced incursions of continental polar air into the country. With the marked warming and accompanying recession of the snowline in the United States resulting from the Gulf of Alaska deepening and related events, any potential refrigerating effects of November's abnormal snow cover and associated stimulation of baroclinic development over warm waters off the United States east coast were nullified.

Finally, the well marked soil-moisture deficit in southern India at the end of November, through reduced evaporative cooling from soil surfaces in December, probably contributed to the above normal surface temperatures and upper-level heights (not shown) during that month in this area of sluggish circulation.

Thus it appears that the picture is one of continuous interplay, with the circulation developing in response to internal and climatic factors and selectively drawing upon potentially influential anomalous surface thermal fields.

## 6. CONCLUSIONS

Major components of the anomalous thermal nature of the earth's surface can be specified for a large portion of the Northern Hemisphere from routinely Available data involving sea-surface temperatures, Arctic sea-ice, middle-latitude snow cover, and soil moisture. Despite the fairly satisfactory condition of these data, certain serious problems do exist. Routine and operationally timely analyses of mean sea-surface temperature do not appear to be available for the North Atlantic Ocean, the Mediterranean Sea, and vast areas of the tropical oceans. Snow-cover data, while widely observed and regionally available, are deleted from synoptic reports prior to overseas transmission. Routine and timely analyses of sea-ice distribution are available for only a small part of the Arctic region. Finally, only the grosser aspects of the soil-moisture distribution can be anticipated in view of assumptions made and empirical techniques applied.

The first three problems appear amenable to solution in terms of the proposed program of World and Regional Weather Centers, as part of the "World Weather Watch," which will provide an optimum blending of satellite and conventional observation techniques. While the potential usefulness of satellite observations in this context cannot be overemphasized, the ever-improving status of conventional data is also an important factor.

The example discussed (November-December 1959) illustrates the circulation-dependent selectivity of the atmospheric circulation in drawing upon anomalous surface influences. The interaction between atmospheric circulation and underlying surface in the November-December 1959 period is interpreted in two areas in relation to climatological persistence. The mid-Pacific upper-level trough of November 1959, under the influence of seasonally increasing westerlies, moved eastward in December to the Gulf of Alaska where its strong intensification was due, in part, to the warm Gulf waters and the intensified horizontal gradient of water temperatures. This Gulf deepening in December brought mild Pacific air across the United States, replacing November's cold continental air. Examination of past November-December sequences indicates that this chain of events has occurred several times and indeed contributes to the established tendency toward non-persistence of November cold temperatures in the United States.

In Eurasia, the Northern European block-Asiatic trough complex persisted from November to December 1959. It is suggested that the thermal nature of the earth's surface may have exerted a persistence-invoking influence in this case. November's warm blocking High extended over an area of relatively sparse snow cover in northern Europe as well as over the Barents Sea which at this time of the year is normally several degrees warmer than the rapidly cooling European continent. The cold Asiatic trough overlay an area where the evidence strongly suggests an extensive and

seasonally abnormal snow cover. It is hypothesized that the underlying surface in this type of synoptic situation is a factor in the established Eurasian climatological persistence of height anomaly from November to December.

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